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TESTING OF CERAMIC GAS TURBINE COMPONENTS UNDER SERVICE-LIKE CONDITIONS

Wilhelm Siebmanns

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16. Abstract

The German firm MTU, Munich, West Germany, is developing gas turbine components in contact with hot gases made of special ceramics (silicon nitride, silicon carbide) which can withstand temperatures up to 1600 K. Various components such as the combustor and turbine wheel are being developed. Various preliminary tests of components are discussed.

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TESTING OF CERAMIC GAS TURBINE COMPONENTS UNDER SERVICE-LIKE CONDITIONS

Wilhelm Siebmanns*)

If all gas turbine components which are in contact with hot gas are manufactured from special ceramics (silicon nitride, silicon carbide), cycle and component temperatures can be increased up to 1600 K. MTU is developing various components, such as combustor and turbine wheel, step by step until they are ready for service. At present, combustors are surviving comprehensive service-like cyclic tests in hot gas at atmospheric pressure (1000 h, 1000 starts per component) without damage. Tests above atmospheric pressure (5 bar) are underway. At MTU, a rotor wheel variant consisting of a metallic hub with inserted single blades is being constructed. The step to aerodynamically contoured airfoils will follow, as soon as the stress problems encountered in connection with the blade rod are fully under control. The program will be completed in 1980 with a test run of a prototype turbine made from ceramic components developed by various companies under the leadership of the DFVLR (Aerospace Research and Testing Institute). The program is being supported by the Bundesministerium fuer Forschung und Technologe (Federal Ministry for Research and Technology). /406**

1. INTRODUCTION

Gas turbines for use as land installation drives in a range between 75 kW to 300 kW are compared against diesel motors because of their economy. This results in processed gas temperatures and

*) Dr. W. Siebmanns, MTU Munich, Div. GWAK, Dachauerstr. 665 D-8000 Munich 50, Germany. Lecture at the DKG Meeting, "High temperature properties of ceramic materials", on February 16-17, 1978, in Baden-Baden.

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therefore component gas temperatures around 1600 K, which can no longer be survived by metals without drastic cooling measures which reduce the efficiency. Therefore, ceramics could play a natural role in this application if it is possible to conform with the following requirements which are exceptionally high:

Mechanical	Tensile loading Strong centrifugal forces Slow and also fast and superimposed oscillation loads Eigen stresses in components with complex shapes Erosion
Chemical	Erosion by hot gas, salt Oxidation
Thermal	Large temperature gradients with respect to time and position Thermal fatigue Temperature alternating loads

If such ceramic materials exist which can withstand such /407 application conditions, according to our present state of knowledge, these should be ceramic materials based on silicon (Si_3N_4 [nitride], SiC [carbide]). The high strength and favorable thermal shock conditions means that production methods for producing complicated components can be developed [1-3].

These materials which are still somewhat foreign to designers or producers have properties which depend on the part shape and manufacturing method previously unknown for metals. Therefore, there was a need for intense collaboration between material producers, designers and users or test engineers. The quality control of parts which undergo dynamic loads require the justification

Fig. 1. Ceramic components for the gas turbine.

Fig. 2. Test stand for ceramic flame tubes.

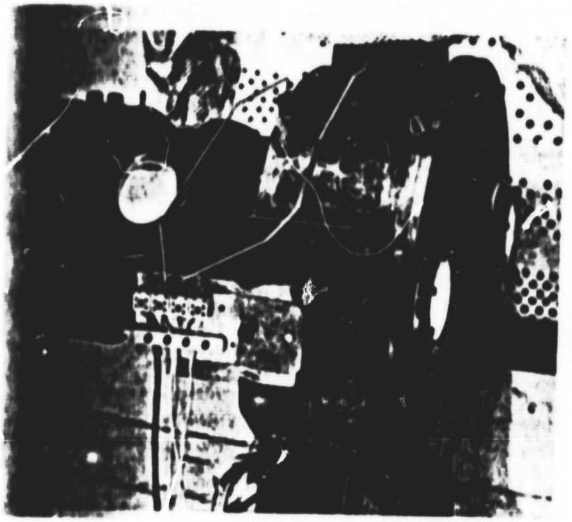

Fig. 3. Test stand for ceramic components in contact with hot gas

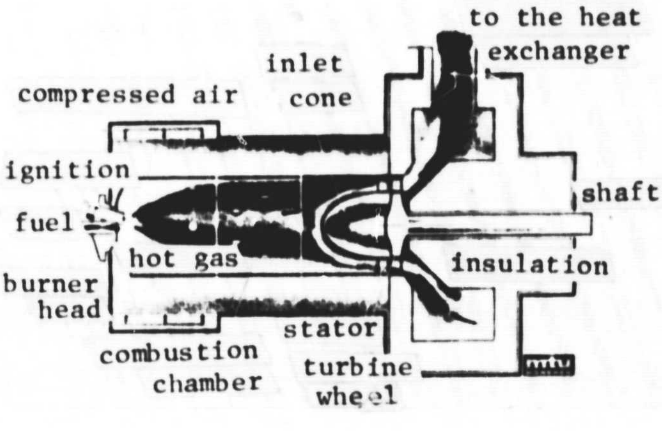

Fig. 4. Functional diagram for the test stand of Fig. 3.

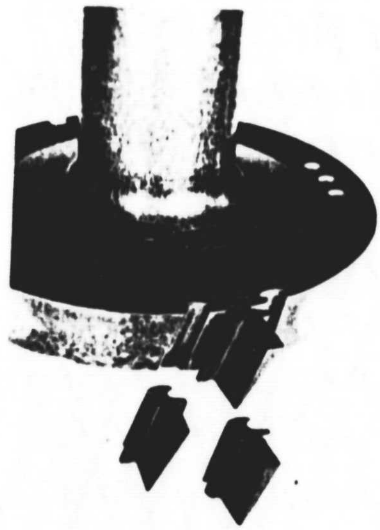

Fig. 5. Partially bladed test loader made of metal with installed ceramic blades.

of all of the manufacturing parameters and the availability of suitable nondestructive test methods, in addition to the usual destructive test parameters. In order to avoid local component overloads and the sudden brittle failure, finite element computing methods are used. In addition, lifetime calculations are formulated on a mathematical-statistical basis, for example, according to Weibull, in order to determine the failure probability of components.

However, all of this effort does not mean that tests are necessary with components during which all of the requirements mentioned at the beginning are realistically simulated, in the form of a changing collection of requirements. From the large number of ceramic gas turbine components (Figure 1), we will discuss the two most interesting ones.

2. THE CERAMIC COMBUSTION CHAMBER

It develops in three steps: A very simple test stand (Figure 2) allows one to heat simple ceramic tube segments made by various manufacturers, made of different materials, and made according to different methods. It has aviation fuel injectors which inject fuel axially, compressed air and electrical ignition. Using the same idea, the behavior for cold starts, the cyclic production of average and high temperatures was determined, as well as the behavior under continuous conditions and during turn-off with cold compressed air injection. Without a great deal of scientific evaluation, we were able to make a preliminary selection of the suitable materials, which also have low costs.

Based on this preliminary selection, we started operations with a test stand (Figure 3) which agreed more with the increased mass throughput for combustion chamber operation because of its extended instrumentation. However, it was not possible to operate at the usual pressure differences of a few bars, but only at atmospheric pressure. Its method of operation is shown in Figure 4.

Here again static and cyclical tests were carried out as described above. However, additional information for the attachment of all ceramic parts in metallic housings shown in Figure 1 are especially important. Information was also obtained about prestressing and sintering, installation and removal, attachment of measurement probes, and other kinds of practical experience for attaching complicated ceramic parts in metallic housings which have a thermal expansion which is about 10 times higher. The materials and a design concept have proven themselves after several iteration steps. Now the emphasis is on obtaining combustion data for a combustion chamber. Test stands and complete instrumentation for measuring temperature profiles, burn-off, air/fuel ratio for different operating points are available. Combustion, exhaust gas and noise development can be optimized. After the conclusion of such rather costly tests, we can introduce the ceramic combustion chamber into a gas generator. We believe we are close to this goal because the number of hours of tests and starts for one component is already about 1000.

3. THE CERAMIC ROTOR

One MTU concept calls for a rotor which consists of a metallic and heat resistant hub and loosely connected ceramic blades, as shown in Figure 5 for a rotor which carries blades along the entire

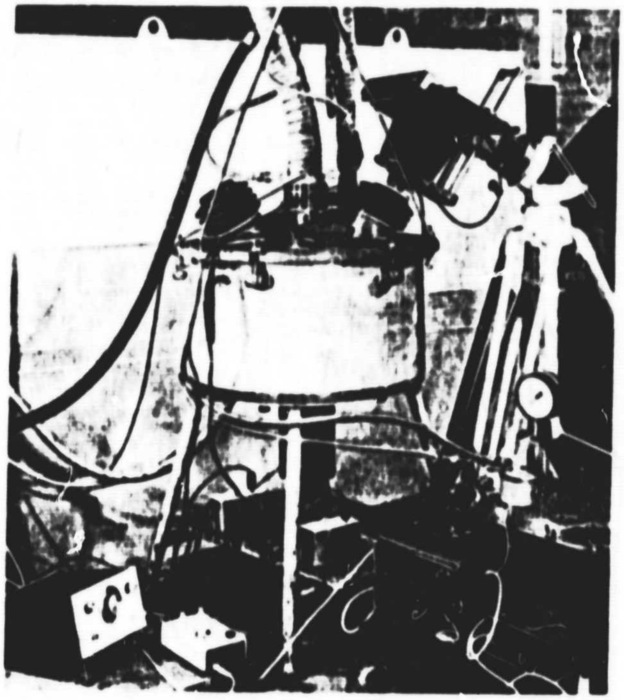

Fig. 6. Centrifugal test stand

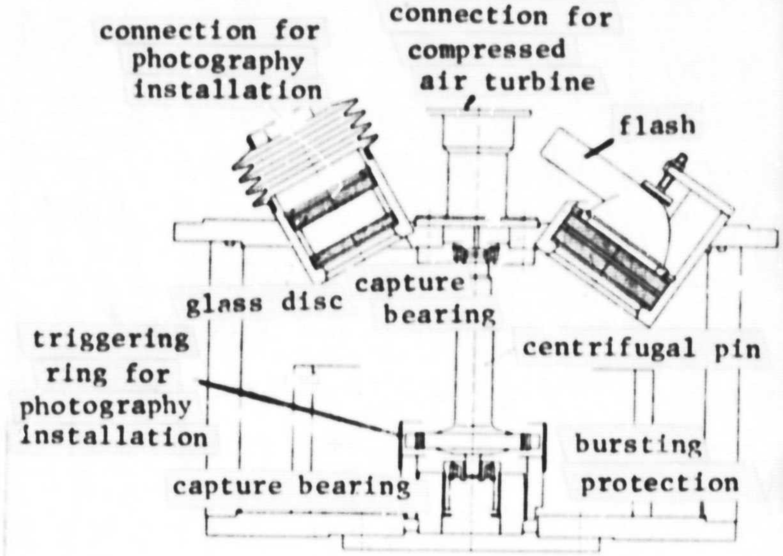

Fig. 7. Functional diagram of the centrifugal test stand Fig. 6

Fig. 8. Highspeed photography of a blade which is just separating (60,000 rpm)

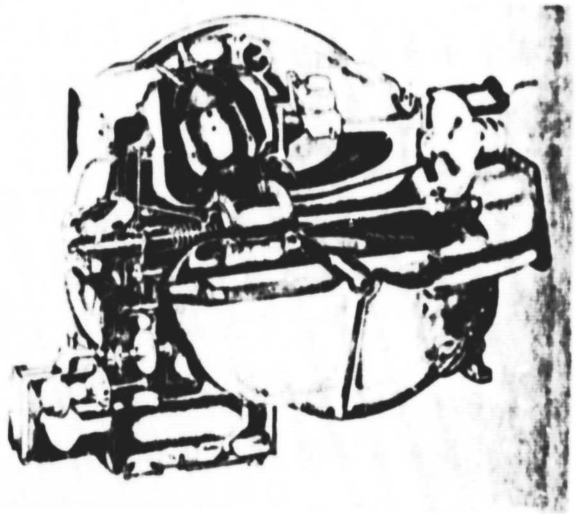

Fig. 9. Vehicle gas turbine

circumference. This type of design is the state of the art for metal wheels. It should be easier to implement with ceramic materials than a completely ceramic wheel, as is being considered at the development partner company Daimler-Benz and VW. The problem of force transmission between ceramics and metal is displaced here to the design of the base of the installed blades, which reduces the transmitted forces with increased number of blades. In the first test in a centrifugal test stand (Figures 6 and 7), a rotor with blades and an independent drive in a vacuum is brought up to the operating rpm or the fracture rpm.

The aerodynamic shape of the fan blade was first approximated by flat surfaces. We obtained information about the design of the blade base, the loads, the surface machining, friction and sintering at the base. High-speed photographs taken at the instant of separation of the blades from the base show the type of failure (Figure 8) and makes it easier to determine the reason for the failure. Present blades can withstand maximum circumferential speeds of more than 500 m/s at their tip. Only after the success of these tests which are important and which are carried out at reduced centrifugal forces at room temperature will test rotors be tested in hot gases from an external gas generator.

The cooled discs warm up to about 1000 K, the blades at hot gas temperatures, i.e., about 1600 K. In spite of the hot gas, such tests are also carried out using a compressed air turbine with an independent drive, because the wheel carries blades along only part of the circumference in order to reduce test costs. Only in the third attempt is a machine close to the design of a turbine with acceptable efficiency being considered. It is now being calculated and constructed and will be tested up to 1980 [4]. After this, we can foresee the development of a real power unit for vehicles, after a new technology is mastered for highest temperatures to replace the internal combustion engine (Figure 9).

We would like to also note that the development of a propulsion system goes beyond the financial capabilities of several firms. Therefore, for the last four years, the German Federal government has carried out common research programs among German ceramic manufacturers, technical school institutes and gas turbine manufacturers which last two years, according to the American example. It is headed by the German research and test facility (DFVLR).

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